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**FACTORS AFFECTING THE SPREAD OF A BIOTERRORIST AGENT
THROUGH A BUILDING**

**A thesis submitted in partial fulfillment of the requirements for Honors Research
in Mechanical Engineering**

By

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University of Arkansas, 2007**

**May 2007
University of Arkansas**

Factors Affecting the Spread of a Bioterrorist Agent Through a Building

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Abstract

Bioterrorism has become a concern for Americans since the 2001 anthrax letters. Many studies have been done regarding the possibilities of biological attacks since, and most deal with possibilities of large scale attacks. However, there is reason to believe that small scale attacks are more likely. Even though studies have been done revolving around the postal system and the spread of bioagents through mail, few if any studies have looked at an attack on a single building.

One particular method of attacking a building would be simply releasing an aerosoled contaminant in the building. This purpose of this project is to develop a method for studying the spread of an aerosoled contaminant through a building and to determine what factors most affect the time between contaminant release and lethal exposure for an occupant in various locations. A multizone airflow model, CONTAM, was used to run several scenarios to compare the effects of the air handling system, opening or closing doors, and which floor an occupant is located.

It was discovered that the air handling system had the greatest effect on a contaminant's spread through a building. Which floor an occupant was on had some effect, although insignificant compared to the air handling system's effect. Opening or closing doors generally was found to be important, but had the least effect on lethal exposure for an occupant. For the scenarios investigated, lethal exposure times ranged from 5 seconds to nearly 15 minutes.

Introduction

Throughout history, biological weapons have been used to wage war. One of the earliest and possibly deadliest examples occurred in the mid-1300s in Kaffa as bubonic plague victims of the Tartar army were catapulted over the city walls. Some believe that this is what led to the epidemic throughout medieval Europe killing 25 million. The twentieth century saw the rise of research into biowarfare among nations across the world. This led to the signing of the Biological Weapons Convention in 1972, which forbids research of offensive biological agents and stockpiling bioweapons for military purposes [5].

Bioterrorism has become a concern for Americans since the September 11 attacks on the World Trade Center because of several incidents involving anthrax. The first occurred on 9/25/2001 when an assistant to Tom Brokaw, an NBC anchorman, began to develop cutaneous anthrax after handling a letter containing a powder. By November 2, 2001 the CDC had reported 21 cases of anthrax (16 confirmed, 5 suspected) [4].

Possible bioterrorist agents/diseases are categorized by the CDC into three categories. Category A Diseases/Agents are the highest priority risks. These agents can easily be transmitted, result in high mortality rates, have potential for major public health impacts, and require special action for public health preparedness. Currently there are six diseases listed by the CDC in this category. They are Anthrax, Botulism, Plague, Smallpox, Tularemia, and Viral Hemorrhagic Fevers. Category B Diseases/Agents are moderately easy to disseminate, have low mortality rates, and require enhanced disease surveillance by the CDC. Category C Diseases/Agents are those considered to be available for mass dissemination, easily produced, and have potential for high mortality rates [3].

In the 2001 anthrax exposures, the terrorists used the postal service to deliver the anthrax. Letters were laced with anthrax powder that postal workers or the letter recipients would be exposed to. One of the most feared means of making a biological attack would be releasing a large amount of some agent into the atmosphere in or over a large city. If someone were to release 100 kg of anthrax over a large city for instance, the disease could kill millions [1].

Such a release is not likely based on historical attacks. Large-scale attempts have been attempted by terrorists in the past, but have all failed. It is likely that terrorist groups lack the funds or technology to succeed in a mass casualty attack. For instance, Aum Shinrikyo failed on ten separate occasions at an open-air urban attack of anthrax or botulism, despite having considerable wealth and scientific capabilities. It is more likely that terrorist attacks will be small scale attacks or merely hoaxes [7].

Problem Statement

One possible means of a small scale attack would use a building's ventilation system to spread a contaminant throughout a building in a matter of minutes to infect everyone in the building. All that a terrorist might need is an aerosol can with some contaminant inside. If the aerosol were placed in a return or intake vent, it would seem that the entire building would be in danger with relatively little difficulty to the terrorist.

The purpose of this study is to examine the effectiveness of such an attack on a generalized building and to provide a method for modeling such an attack for future buildings. The time between contaminant release and the time at which an occupant is exposed to a lethal dose will be compared for various scenarios in order to determine what factors contribute most to occupant exposure.

Modeling Method

In order to analyze this type of threat, airflow modeling software is required. CONTAM is an example of such software. CONTAM is a multizone indoor air quality and ventilation analysis computer program capable of determining airflows contaminant concentrations and personal exposures. Using CONTAM, the movement of a bioagent through a building can be predicted by knowing the building's layout and ventilation system.

The first step in using CONTAM is to draw a sketch of the building to be analyzed including all walls, ducts, and airflow paths (windows, doors, wall leakages, cracks, etc.). Next the elements of the sketch are defined in the program. For example, the dimensions of vents, fan flow curves, and zone sizes are all inputted. Next, information on any contaminants are inputted along with the location and method of entering the building. Finally, the program is ready to analyze the airflow for the building using a number of available simulation methods.

For this study, a simple building was sketched to model several different scenarios. The building is two stories tall; both floors have a large open space meant to represent a cubicle area; along two opposite sides of the building on each floor are smaller rooms representing offices. Below, the CONTAM sketches for each floor are shown in Figure 1. A description of icons on the sketch is given in Appendix A, and details of the specifications used for this project are given in Appendix B.

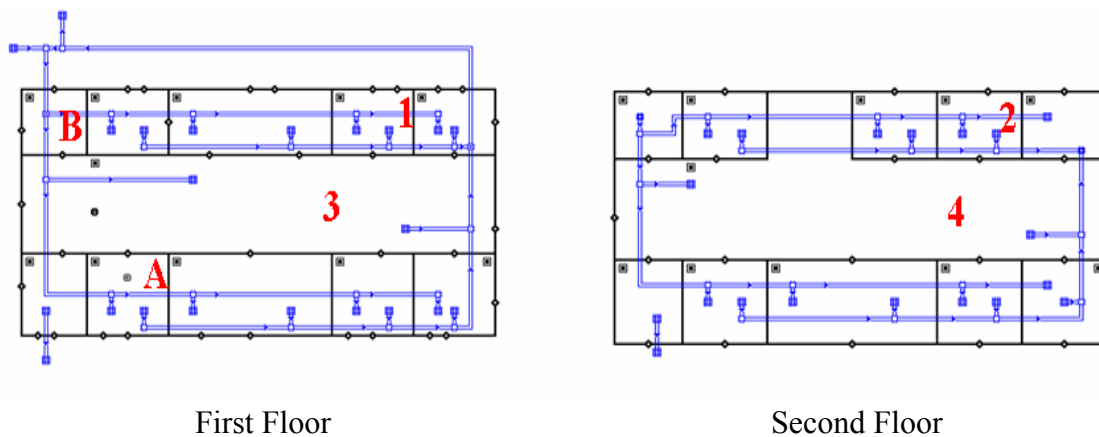


Figure 1. CONTAM building sketch

For the scenarios, a burst contaminant source was placed in a first floor office (location A) and a first floor maintenance room (location B). The source would burst 0.4 kg of an aerosol contaminant into the model at 10:00 AM. Simulations were run with all of the doors in the building open and closed and exposure results were calculated in an office (locations 1,2) and in the cubicle area (locations 3,4) on each floor, giving a total

of sixteen scenarios. The burst source is representative of and aerosoled release of an agent. The office was chosen to represent a release location with full ventilation whereas the maintenance room has no ventilation.

CONTAM exports results for contaminant concentrations for every zone for each time step set for the simulation. Five second increments were used for these simulations, although it was discovered after running the scenarios and calculating all the data that smaller increments should have been used. To determine exposure for a person in each room, Microsoft Excel was used to integrate the data numerically. These calculations were based on an inhalation rate of 20 m³/day, and an LD50 of 0.01 micrograms.

The LD50 value chosen is calculated for Inhalation Anthrax from the low end of the University of Alabama, Birmingham's LD50 estimate of a 10,000-20,000 spores [2] and Ed Lake's concentration estimate of one trillion spores per gram [6]. For the calculations, a 1% solution was assumed for the aerosol device, so the times until lethal exposure were based on 1 microgram of aerosol exposure. The value of 20 m³/day was averaged from values used in several sources ranging from 15 m³/day to 24 m³/day. For future use of this type of simulation, more precise values for particular LD50's and inhalation rates may be applied, but for the purpose of comparing exposure factors, these estimates will suffice.

Results and Discussion

Below is a table of the resulting times until lethal exposure for each of the sixteen scenarios. The table is organized based on where the contaminant was released (Office or Maintenance), where exposure was calculated for an occupant (1st Floor Office, etc) and whether the doors in the building were open or closed. The data is listed in mm:ss format.

| | | Exposure Location | | | | | | | |
|--------------------|-------------|------------------------------|--------|--------------------------------|--------|------------------------------|--------|--------------------------------|--------|
| | | 1 st Floor Office | | 1 st Floor Cubicles | | 2 nd Floor Office | | 2 nd Floor Cubicles | |
| Doors Open/Closed: | | Open | Closed | Open | Closed | Open | Closed | Open | Closed |
| Contaminant Origin | Office | 00:40 | 00:35 | 00:05 | 00:10 | 00:55 | 00:40 | 1:25 | 01:05 |
| | Maintenance | 04:40 | 06:10 | 00:45 | 00:55 | 08:35 | 08:05 | 12:35 | 14:45 |

Table 1. Time to Lethal Exposure (mm:ss)

For each room, the contaminant level and exposure level had similarly shaped graphs as functions of time. A sample set of graphs is given below for the scenario in which the contaminant originates in a first floor office, doors are open, and exposure is measured in the first floor cubicle area, and for the scenario in which the contaminant originates in the first floor maintenance room with same exposure location. These graphs however are given over a much larger time range than the time to lethal exposure. Graphs for each scenario studied are listed in Appendix C. The major differences in the contaminant level graphs for different scenarios are the steepness of the initial increase and where the peak is, both in time and magnitude. The slope of the line for exposure level is proportional to the magnitude of the concentration level.

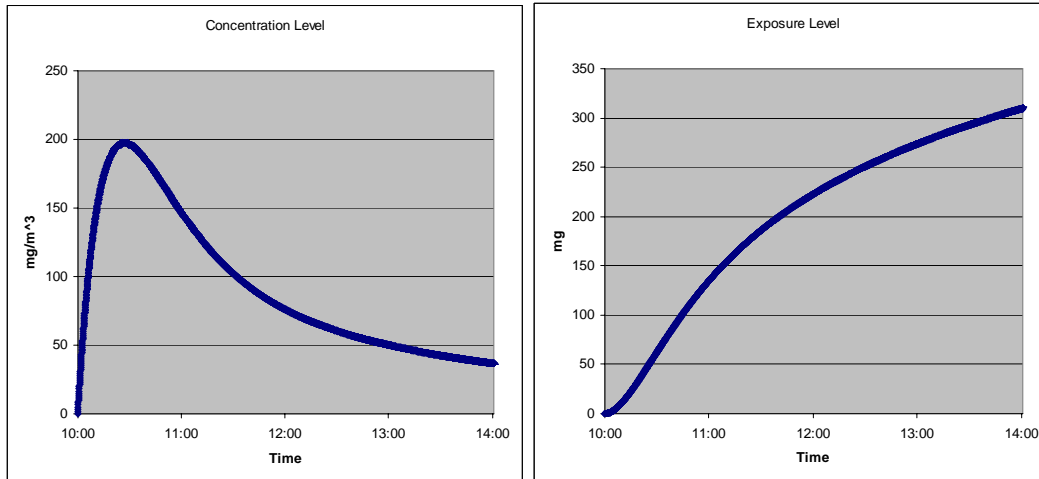


Figure 2a – 1F office to 1F Cubicles
Contaminant concentration and exposure level vs. time

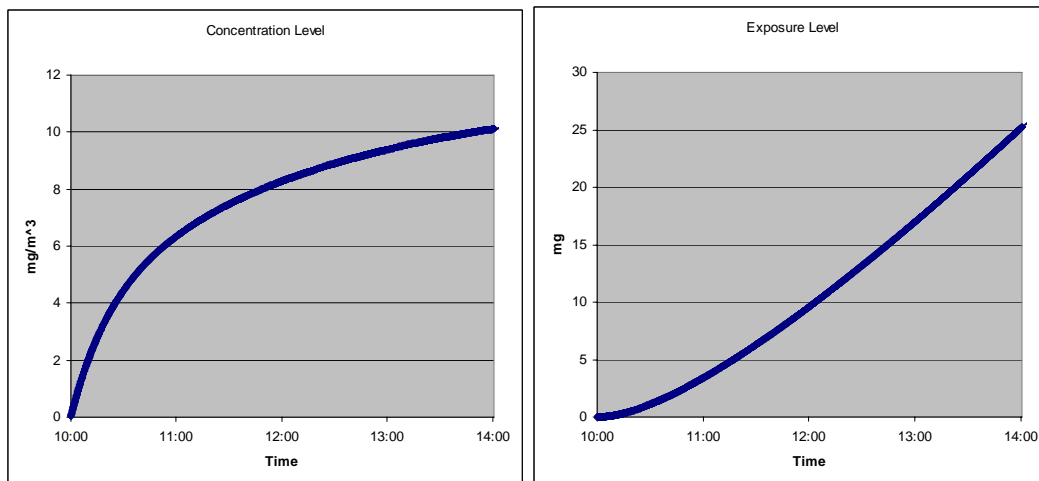


Figure 2b – 1F Maintenance to 1F Cubicles
Contaminant concentration and exposure level vs. time

The three main factors that can be seen in this study are that of the Air Handling System (AHS), whether or not doors are open or closed, and which floor an occupant is on. The largest effect was that of the AHS, followed by the occupant's floor, and the state of the doors in the building had the least effect.

The effect of the AHS is seen by comparing exposure time between scenarios with the contaminant originating in the maintenance room with no ventilation and the office. For an exposure in the same room, it would take 5 to 14 times as long for a lethal dose to be reached when the contaminant originated in the maintenance room as compared to the office. The worst case, when originating in the maintenance room, was just 45 seconds in the adjoining cubicle area with open doors. Most cases in which the contaminant originated in the maintenance room, however, had several minutes of exposure time. This is most likely because the contaminant would have to first exit the maintenance room through relatively stagnant airflows before it could be spread through the building in the AHS. When the contaminant originated in the office, the best case for an occupant was 1:25 with exposure on the second floor.

The effect of the floor an occupant is located on relative to the contaminant is most noticeable in situations with the contaminant originating in the maintenance room. In the scenarios studied, it would only be beneficial to be on the second story if those situations. If the contaminant originated in an office, a person would become lethally exposed by simply traveling through the first floor cubicle area. When the contaminant originates in the maintenance room, however, the contaminant level in the cubicles is low enough that a person could breathe for a few seconds before becoming lethally exposed. The only data that seems to be out of place when comparing differences between floors is comparing the contaminant going from the maintenance room to each of the cubicle areas. Seemingly there is too great of a difference between the sets of times, but this difference would have been largely due to the AHS, as discussed above.

It would have been expected that with a contaminant originating on the first floor the exposure times on a separate floor would be nearly equal in each second floor room. In the scenarios run, however, the second floor cubicle area consistently had a longer exposure time than the second floor office room. This is suspected to be caused by unequal air circulation between the rooms. If one room has a higher air exchange rate, it would follow that the AHS would deliver a contaminant to that particular room at a higher rate as well. This fluctuation between rooms on the same floor would be different for each building modeled since it is dependent on the particular ductwork of a building.

Having open or closed doors affected the outcome the least through the sixteen scenarios. Additionally, the effect was dependent on the specific scenario. In cases where the exposure data was taken in an adjoining room to the contaminant release and in nearly every case where the contaminant originated in the maintenance room, it was better to have doors closed. When the contaminant originated in the office room, having the doors open was better in every exposure room excluding the adjoining cubicle area. This reversal is most likely because more of the contaminant escapes through an open door leaving less to enter the AHS which supplies the rest of the building.

In the cases in which having the doors closed caused a faster exposure time, the exposures were taken in rooms farther from the source than in the cases with the same origin yet having doors closed lengthened the time. This is most likely because when the doors are closed, more of the contaminant is forced through the AHS and so it spreads through the building more evenly, whereas if the doors are open, some of the contaminant would travel through the doorway, leaving less to enter the AHS. This would cause rooms close to the origin to get to a lethal exposure level sooner and rooms far from the origin to get to the same level slower if doors were open.

Conclusions and Recommendations

In the event of an attack on a building similar to the one sketched in this study, it is clear that any AHS should be shutoff as soon as a threat is discovered, although the threat would need to be detected virtually immediately. With the AHS on occupants of a building would have only seconds before being lethally infected by an agent. Occupants should evacuate the building immediately, and in this scenario, should attempt to breathe as little as possible while evacuating. Traveling through the room with the highest contamination (barring the contaminant's origin) would not expose a person to the LD50

immediately. This is because the exposure times calculated in this study reflect a summed exposure amount, not a time at which one breath of air would be fatal.

For the initial simulations and calculations, the wrong value for the LD50 of anthrax was calculated to be 0.1 mg which put the lethal exposure times between 10 minutes and 6 hours. With these times, the assumption that air inside each zone is evenly mixed is a valid enough assumption. However, with the corrected LD50 and times on the order of seconds, this assumption most likely introduces some significant error. For instance contaminant through an office door to the cubicle area would not immediately expose everyone in the cubicle area to a lethal dose, but would take time to spread through the room. The contaminant entering from the AHS would be close to evenly mixed throughout the area, however, so it is difficult to say exactly how much time people have in that room.

Also, the LD50 for other bioterrorist agents may be much larger than anthrax, which would lengthen the exposure times. More agents should be considered for future studies, but for the purpose of studying the factors in a contaminant's flow through a building, studying only anthrax was sufficient.

Many effects that were not considered in this study could still be studied with CONTAM. These include the effects of outside windows, shutting off an AHS after release of an agent, filters and filter efficiencies, multiple AHS buildings, etc. To be fully prepared for the type of bioterrorist attack examined in this study, a model of a specific building should be made, and multiple scenarios should be run for that particular building to determine what procedures will minimize the occupants exposures.

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Appendix A. CONTAM Symbols



Zone Icon



Airflow Path



Contaminant Source



Ducts



Air Vent

Appendix B. Building Details and Specifications

Closed Door

Type: One-way flow using powerlaw
Formula: Leakage area data (per item)
Leakage area per item: 102 cm^2
Reference Pressure drop: 37.5 Pa
Discharge coefficient: 1
Flow exponent: 0.5

Open Door

Type: Two-way flow
Formula: One-opening
Height: 2.1 m
Width: 0.9 m
Minimum delta T for 2-way flow: 0.01 C
Discharge coefficient: 0.78
Exponent: 0.5

Exterior Wall (one path connecting each wall section on East and West side)

Type: One-way flow using powerlaw
Leakage area data (per unit area)
Leakage area per unit area: $4.1 \text{ cm}^2 / \text{m}^2$
Reference Pressure drop: 4 Pa
Discharge coefficient: 1
Flow exponent: 0.65

Exterior Wall (one path connecting each wall section on North and South side)

Type: One-way flow using powerlaw
Formula: Leakage area data (per unit area)
Leakage area per unit area: $1.14 \text{ cm}^2 / \text{m}^2$
Reference Pressure drop: 4 Pa
Discharge coefficient: 1
Flow exponent: 0.65

Window (one path on each wall section on North and South side)

Type: One-way flow using powerlaw
Formula: Leakage area data (per unit length)
Leakage area per unit length: $0.65 \text{ cm}^2 / \text{m}$
Reference Pressure drop: 4 pa
Discharge coefficient: 1
Flow exponent: 0.65

Zones Floor Areas

Offices/Maintenance/Bathroom: 400 ft²

Lobby/Executive office: 800 ft²

Cubicles: 2400 ft²

Main AHS Supply Fan

Type: Fan element

Formula: Cubic polynomial fit

Cut-off ratio: 0.1

Equivalent orifice area: 0.75 ft²

Shape: circle

Diameter: 15 in

Leakage rate: 0.0075 L/s/m²

At dP static of 1 Pa

Leakage class: 7.5 Sl

Fan Curve Data

| Flow rate (scfm) | Pressure Rise (Pa) | Revised dP |
|------------------|--------------------|------------|
| 0 | 10 | 10 |
| 1000 | 9.5 | 9.5 |
| 3000 | 6.9 | 6.9 |
| 4000 | 4.0 | 4.0 |

Main AHS Return Fan

Type: Fan element

Formula: Cubic polynomial fit

Cut-off ratio: 0.1

Equivalent orifice area: 0.75 ft²

Shape: circle

Diameter: 12 in

Leakage rate: 0.0075 L/s/m²

At dP static of 1 Pa

Leakage class: 7.5 Sl

Fan Curve Data

| Flow rate (scfm) | Pressure Rise (Pa) | Revised dP |
|------------------|--------------------|------------|
| 0 | 9 | 9.0 |
| 900 | 8.4 | 8.4 |
| 2500 | 7.0 | 7.0 |
| 3600 | 4.0 | 4.0 |

Main AHS Return Exhaust Fan (Vents return air to surroundings)

Type: Fan element
Formula: Cubic polynomial fit
Cut-off ratio: 0.1
Equivalent orifice area: 0.75 ft²
Shape: circle
Diameter: 12 in
Leakage rate: 0.0075 L/s/m²
At dP static of 1 Pa
Leakage class: 7.5 SI

Fan Curve Data

| Flow rate (scfm) | Pressure Rise (Pa) | Revised dP |
|------------------|--------------------|------------|
| 0 | 10 | 10 |
| 90 | 9.5 | 9.5 |
| 180 | 8.0 | 8.0 |
| 270 | 4.5 | 4.5 |

Bathroom Exhaust Fan

Type: Fan element
Formula: Cubic polynomial fit
Cut-off ratio: 0.1
Equivalent orifice area: 0.75 ft²
Shape: circle
Diameter: 8 in
Leakage rate: 0.0001 L/s/m²
At dP static of 1 Pa
Leakage class: 0.1 SI

Fan Curve Data

| Flow rate (scfm) | Pressure Rise (Pa) | Revised dP |
|------------------|--------------------|------------|
| 0 | 5.0 | 5.0 |
| 40 | 4.6 | 4.6 |
| 70 | 3.5 | 3.5 |
| 85 | 2.5 | 2.5 |

Ductwork

Type: Darcy-Colebrook resistance
Roughness: 0.15 mm
Shape: circle
Diameter: 15, 12, 10 in.
Leakage rate: 0.0075 L/s/m²
At dP static of 1 Pa
Leakage class: 7.5 SI
Length: depends on segment

Contaminant Data

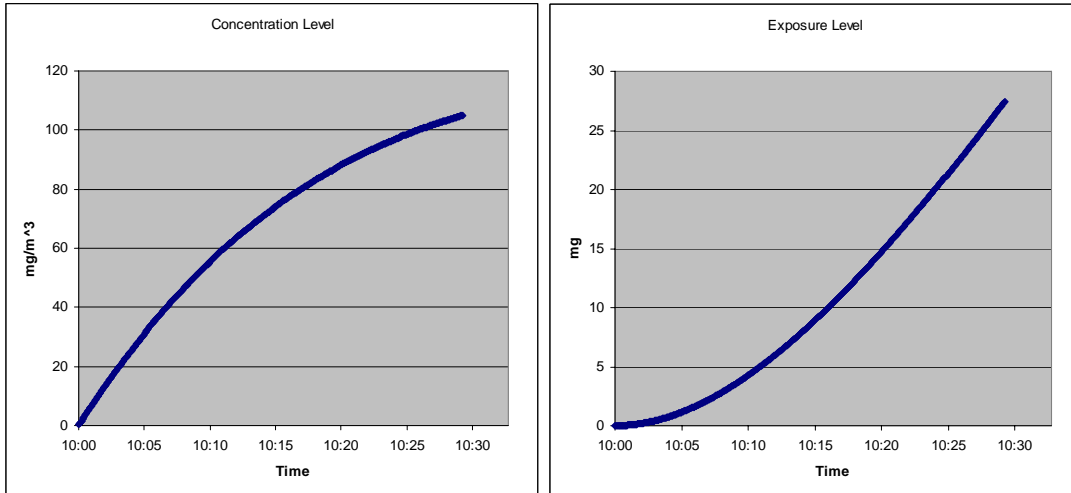
Molecular Weight: 18 kg/kmol
Diffusion Coefficient: 2E-5 m²/s
Mean Diameter: 3 μm
Effective Density: 70.74 g/cm³
Specific Heat: 0
Decay Rate: 0
Default Concentration: 0
Trace Contaminant: Trace
Use in Simulation: Use

Contaminant Source

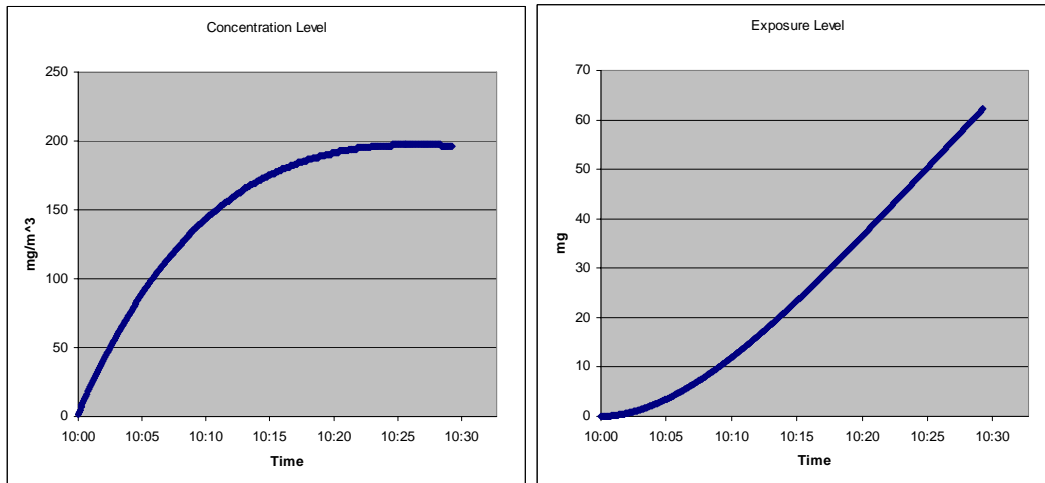
Model: Burst Source Model
Formula: $S(t) = \text{Mass}$
Mass Added to Zone: 0.4 kg
Release Time: 10:00:00

Appendix C – Results Graphs

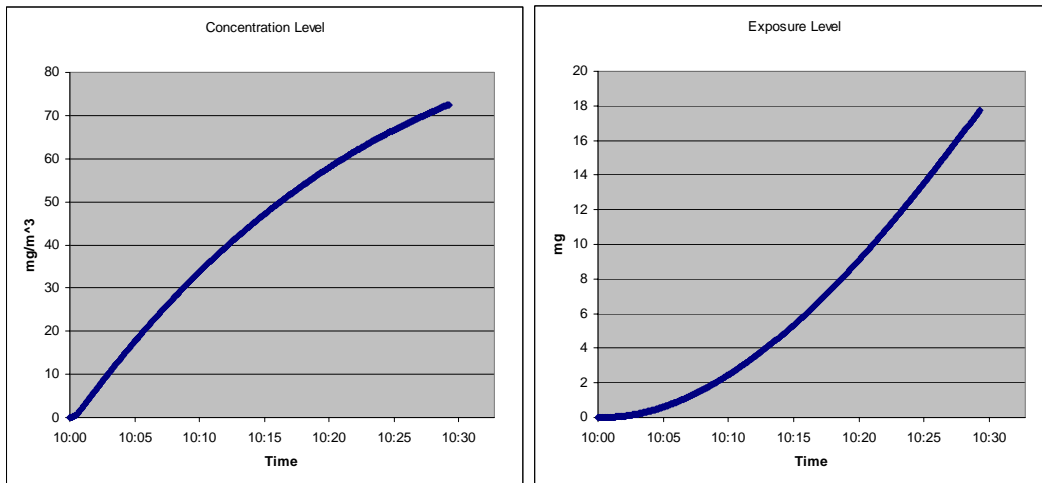
1. Origin: 1st floor office Exposure: 1st floor cubicles Doors Closed



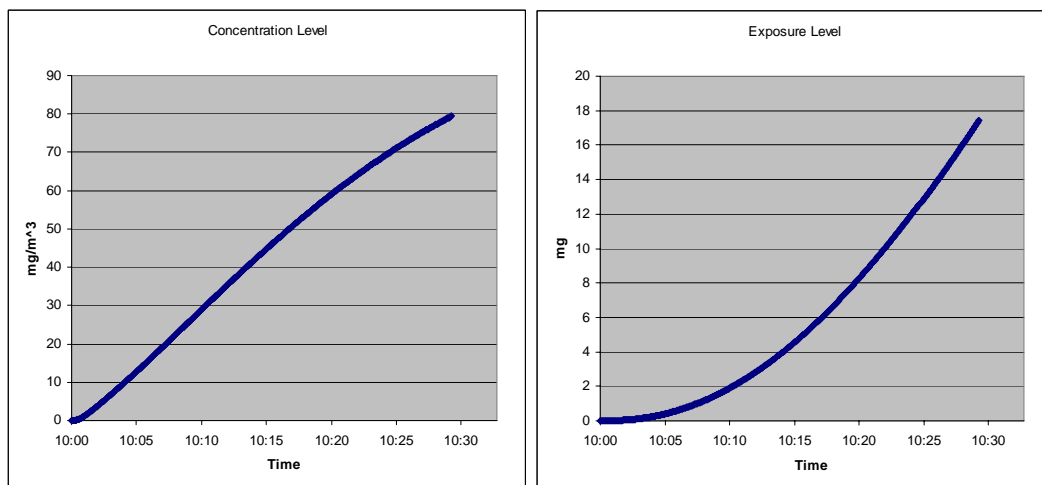
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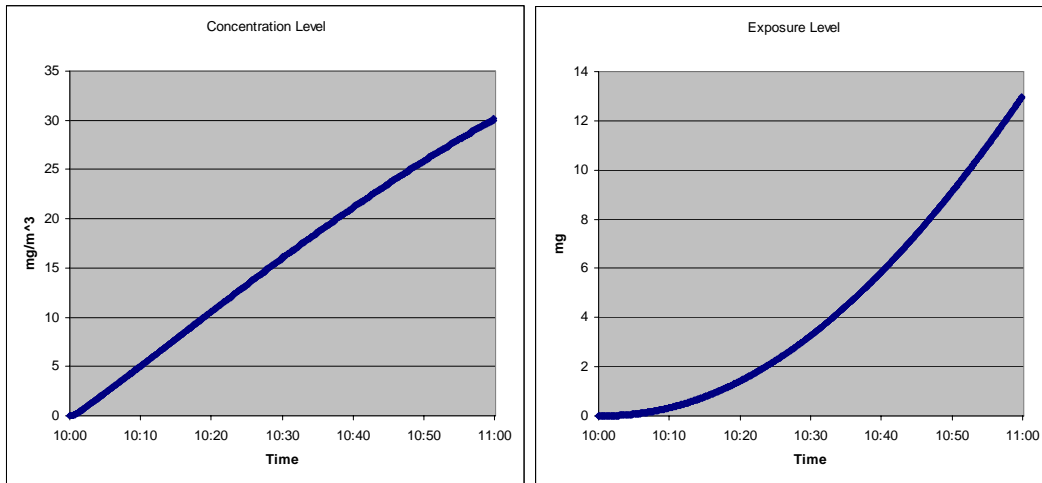
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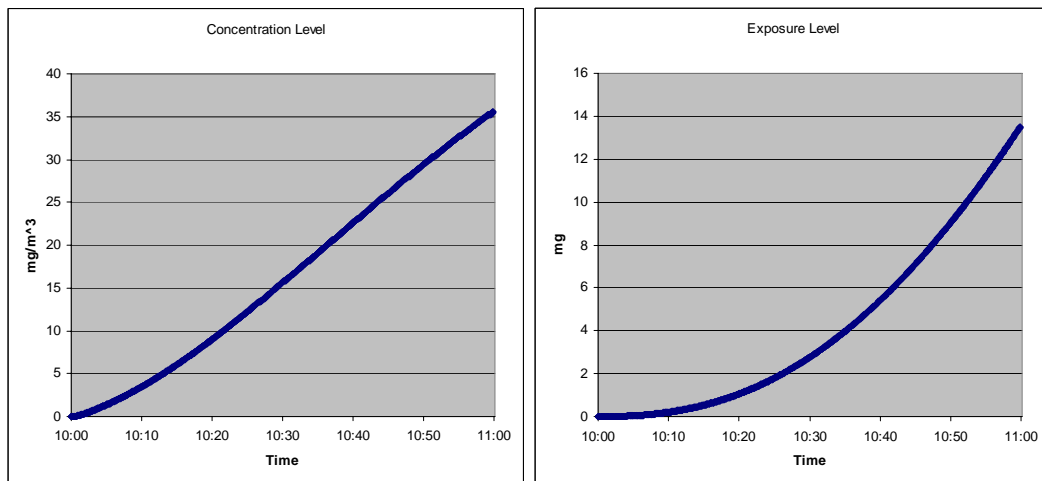
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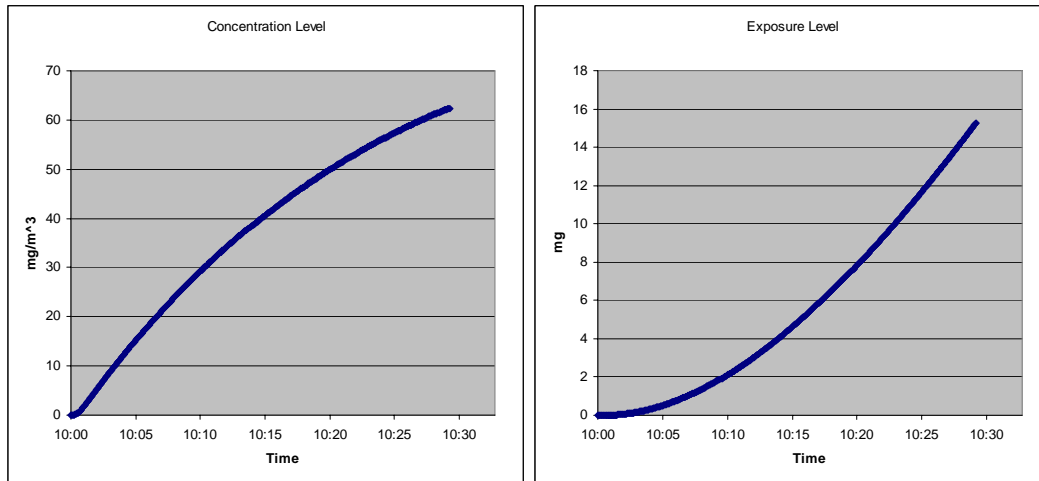
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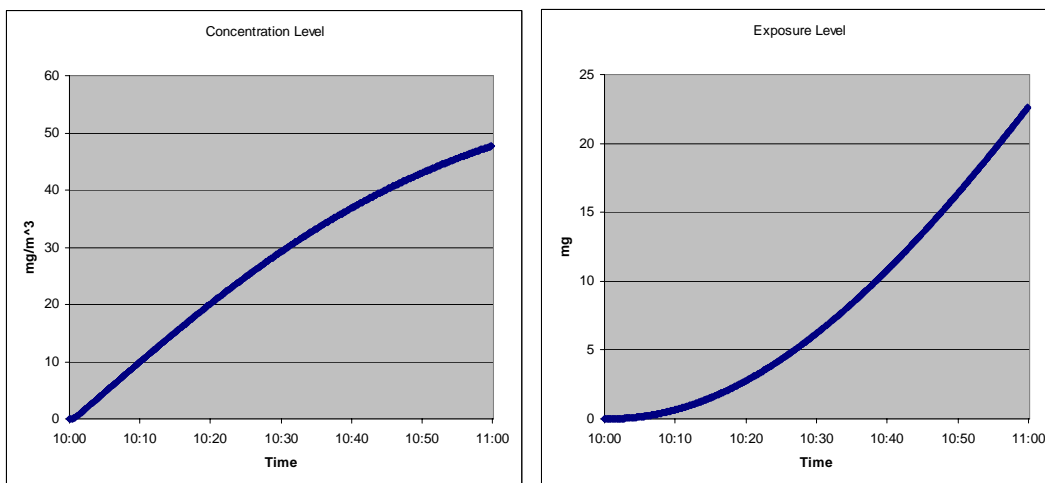
6. Origin: 1st floor office Exposure: 2nd floor cubicles Doors Open



7. Origin: 1st floor office Exposure: 2nd floor office Doors Closed



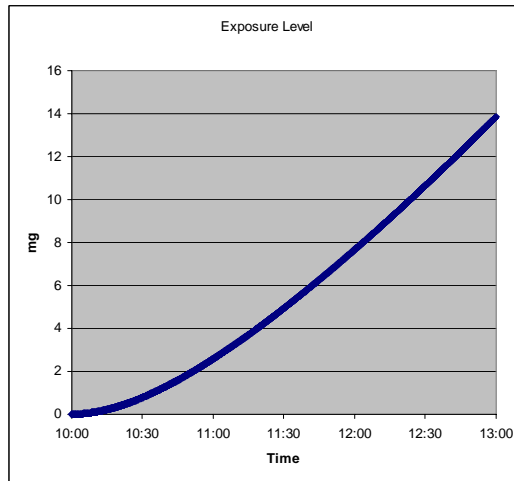
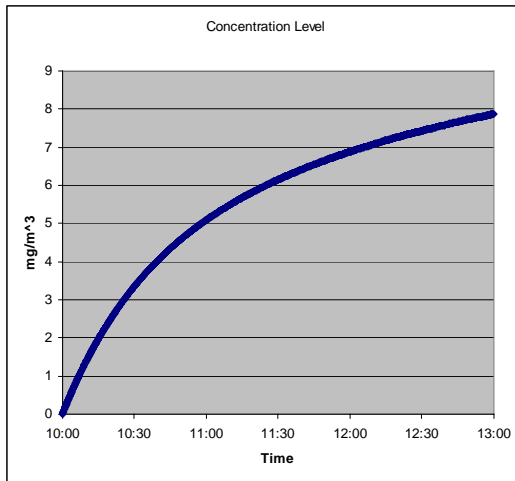
8. Origin: 1st floor office Exposure: 2nd floor office Doors Open



9. Origin: 1st Floor Maintenance

Exposure: 1F cubicles

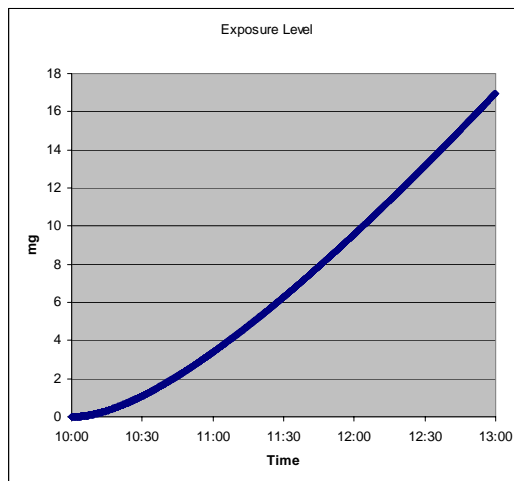
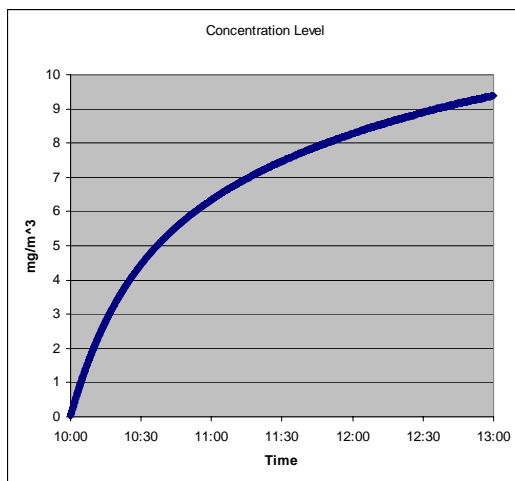
Doors Closed



10. Origin: 1st Floor Maintenance

Exposure: 1F cubicles

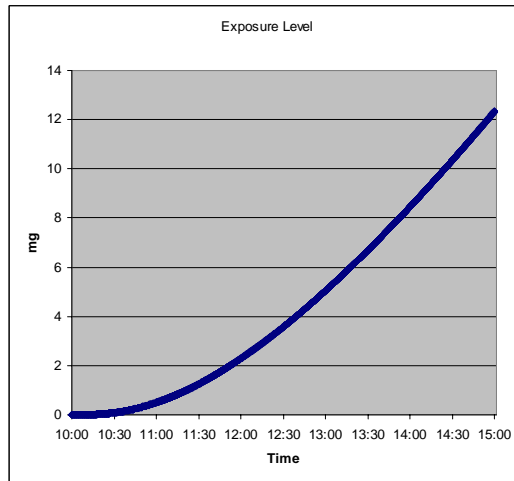
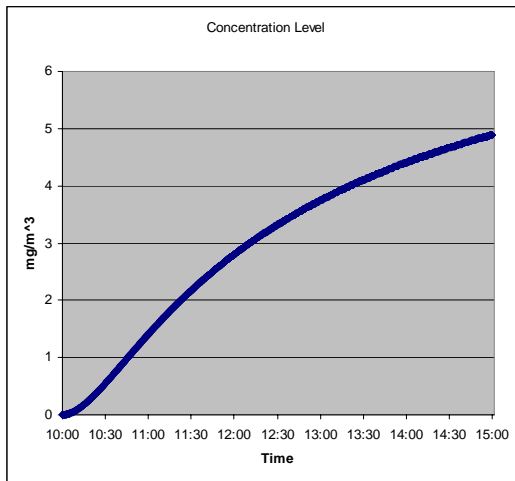
Doors Open



11. Origin: 1st Floor Maintenance

Exposure: 1F office

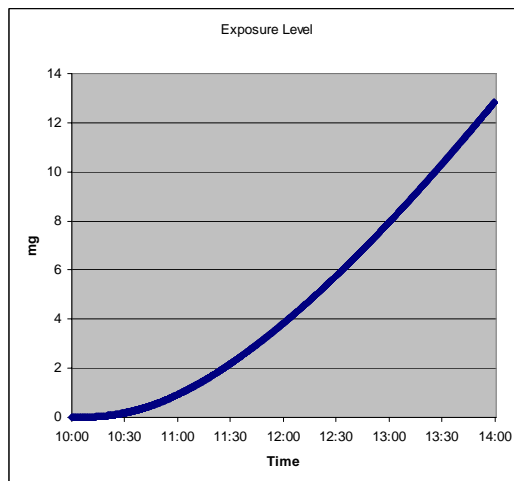
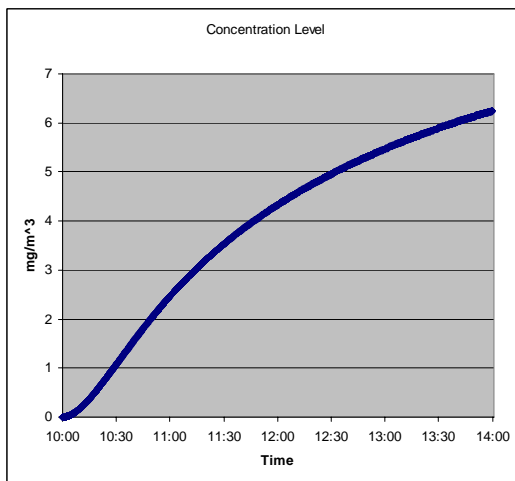
Doors Closed



12. Origin: 1st Floor Maintenance

Exposure: 1F office

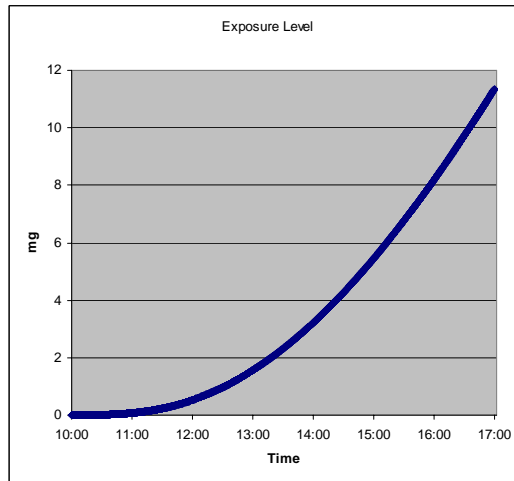
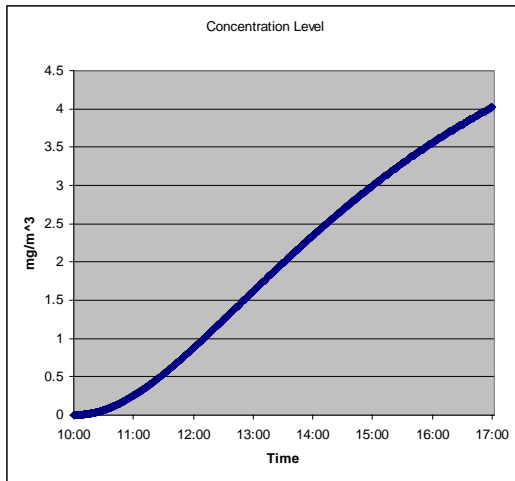
Doors Open



13. Origin: 1st Floor Maintenance

Exposure: 2F cubicles

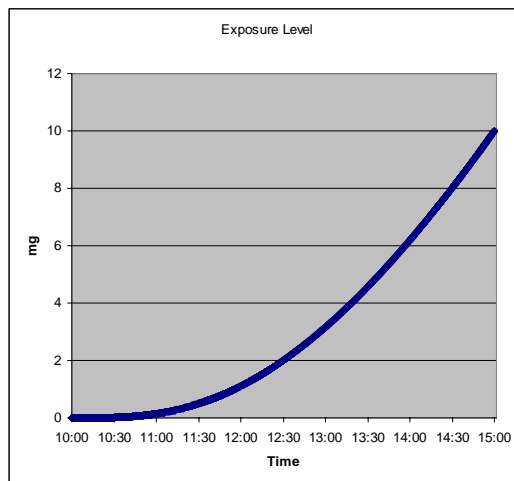
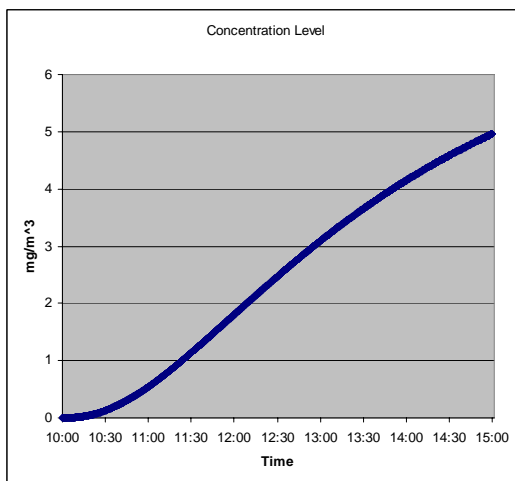
Doors Closed



14. Origin: 1st Floor Maintenance

Exposure: 2F cubicles

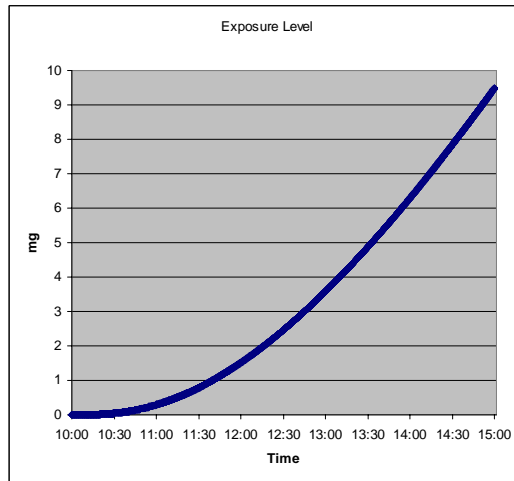
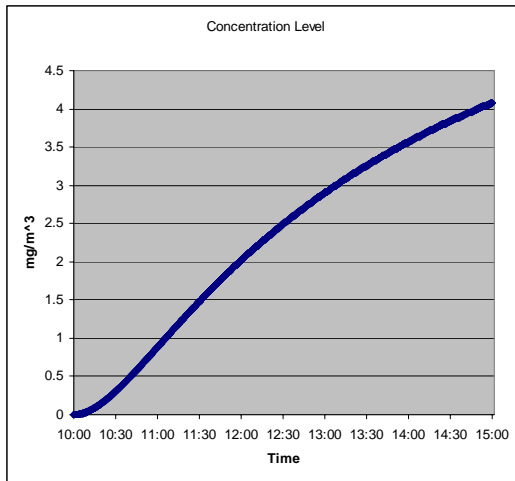
Doors Open



15. Origin: 1st Floor Maintenance

Exposure: 2F office

Doors Closed



16. Origin: 1st Floor Maintenance

Exposure: 2F office

Doors Open

